Quaternary sediments and bedrock geology in the outer Oslofjord and northernmost Skagerrak

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Shallow seismic (sparker), magnetic and bathymetric profiling were carried out on two cruises in the outer Oslofjord in 1979 and 1980.

The survey area is characterized by deep silled basins defined by the main structural trends of the surrounding land area. The Quaternary sediments, largely restricted to these major basins, can be divided into three main units of supposed pre-Weichselian to Holocene age. Most of the sediments were probably deposited during relatively short time intervals in the Late Weichselian under ice-proximal conditions, and in the early Holocene.

Magnetic total field and seismic data were used to map the submarine outlines of the Permo-Carboniferous Vestfold lavas, the Permian sedimentary rocks and the Larvikite body. The presence of other intrusives in the eastern and southern part of the survey area is discussed.

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The survey area is situated in the southern part of the Permo-Carboniferous Oslo Graben, a downfaulted block of Paleozoic rocks, about 50 km wide and more than 200 km long in a north-northeasterly direction (Ramberg 1976). The subsidence is of the order of 1000–3000 m relative to the surrounding Precambrian gneisses. The graben is thought to be linked south-westward to the North Sea graben system, in the Skagerrak. Both the bedrock and Quaternary geology on land around the Oslofjord have been investigated in detail (Holtedahl 1960, Feyling-Hanssen 1964, Ramberg 1976, Sørensen 1979), but the submarine part has received relatively little attention. During 1963–64, the Norwegian Geotechnical Institute (NGI) carried out a geophysical survey under the Oslofjord Project (Richards 1976), but the sediment thickness obtained in some of the deeper basins was underestimated, as shown later in this paper.

To augment the data base on the submarine parts of the Oslofjord area, the Department of Geology, University of Oslo, carried out two marine geophysical cruises in the outer Oslofjord in 1979 and 1980 with the main objectives:

1. to map the distribution of Quaternary sediments
2. to obtain information on the stratigraphy and discuss the depositional history and the sedimentary processes involved
3. to map the submarine bedrock geology and structural pattern.

In this paper we present data and results obtained during both cruises.

Data acquisition

The survey area extends from the island of Bastøy and as far south as the island of Jomfruland (Fig. 1). The 1979 cruise (Fig. 2) was performed with the R/V "H. U. Sverdrup". Precise navigation was obtained with a Motorola mini-ranger system (accuracy approximately 10 m), supplemented with Decca main chain for the outermost lines. The geophysical instrumentation consisted of an Elsec proton magnetometer, a hull-mounted 12 kHz Simrad echo sounder and a shallow seismic E G & G Sparker system with an energy output of 1 kJ. The data were band-pass filtered (50–400 Hz) and recorded on an analogue recorder.

The weather conditions were generally good in the inner part of the survey area, while winds up to gale strength reduced data quality on the outer lines. The ship's speed was approximately 5 knots.

The 1980 cruise (Fig. 2) was performed with the R/V 'Bjørn Føyn', to supplement the magnetic measurements of 1979. The navigation was

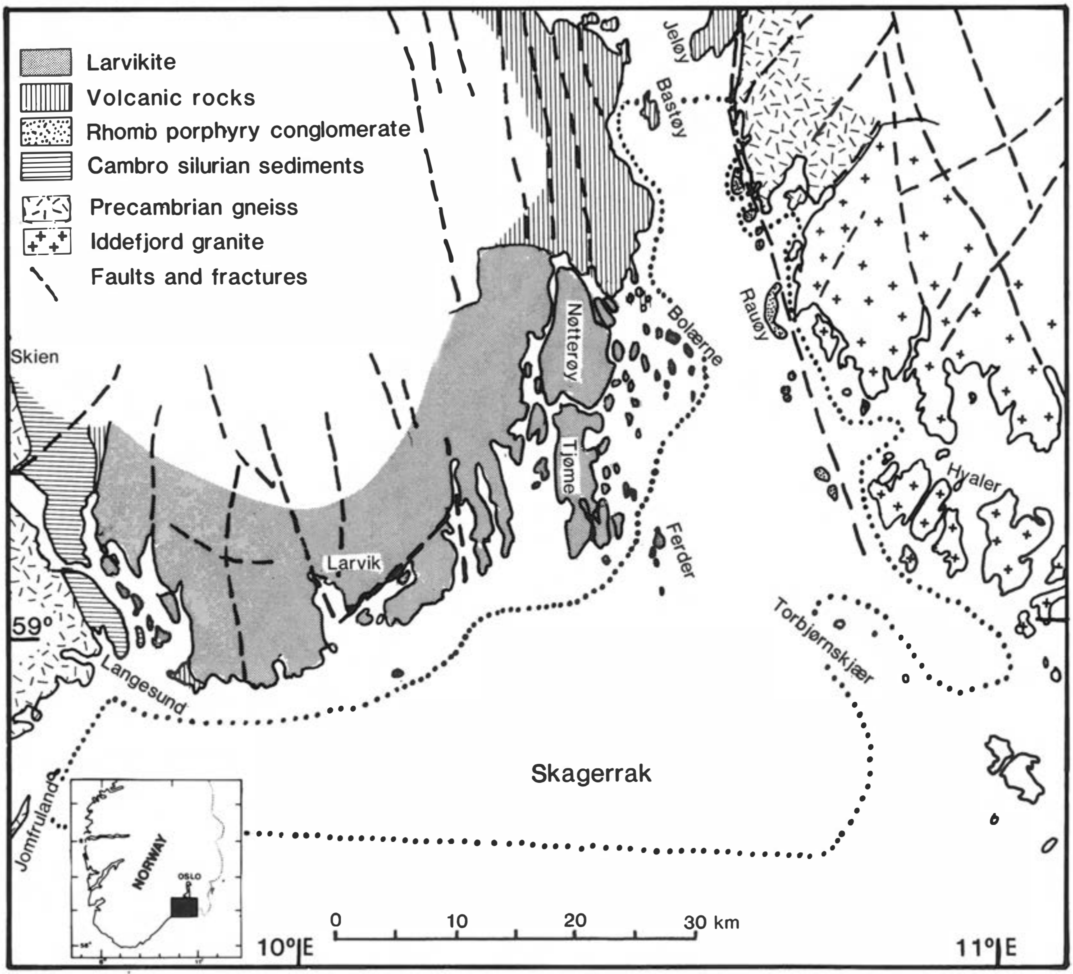


Fig. 1. Geological map of the coast surrounding the survey area (outlined by dotted line). Also to be used for location of names used in the text. (Simplified after Ramberg & Larsen 1978, Iddefjord granite after Grønlie et al. 1980.)

based on radar ranging in the fjord, and Decca main chain outside the island of Ferder. The instrumentation consisted of a hull-mounted 38 kHz echo sounder and an Elsec proton magnetometer.

Weather conditions during this cruise were good and the ship's speed was held at approximately 8 knots.

All analogue records were digitized and stored as time series. For the seismic records, the sea floor and the bedrock surface were digitized to calculate total thickness of Quaternary sediments.

Geological setting of the survey area

Bedrock

Fig. 1 shows a simplified map of the land geology surrounding the survey area. The main lithologies are:

- Precambrian gneisses on the east side of the major fault line, the Oslofjord fault (Ramberg 1976).
- Precambrian Iddefjord granite in the very southeastern part of the area. This granite body is linked to the Swedish Bohus granite

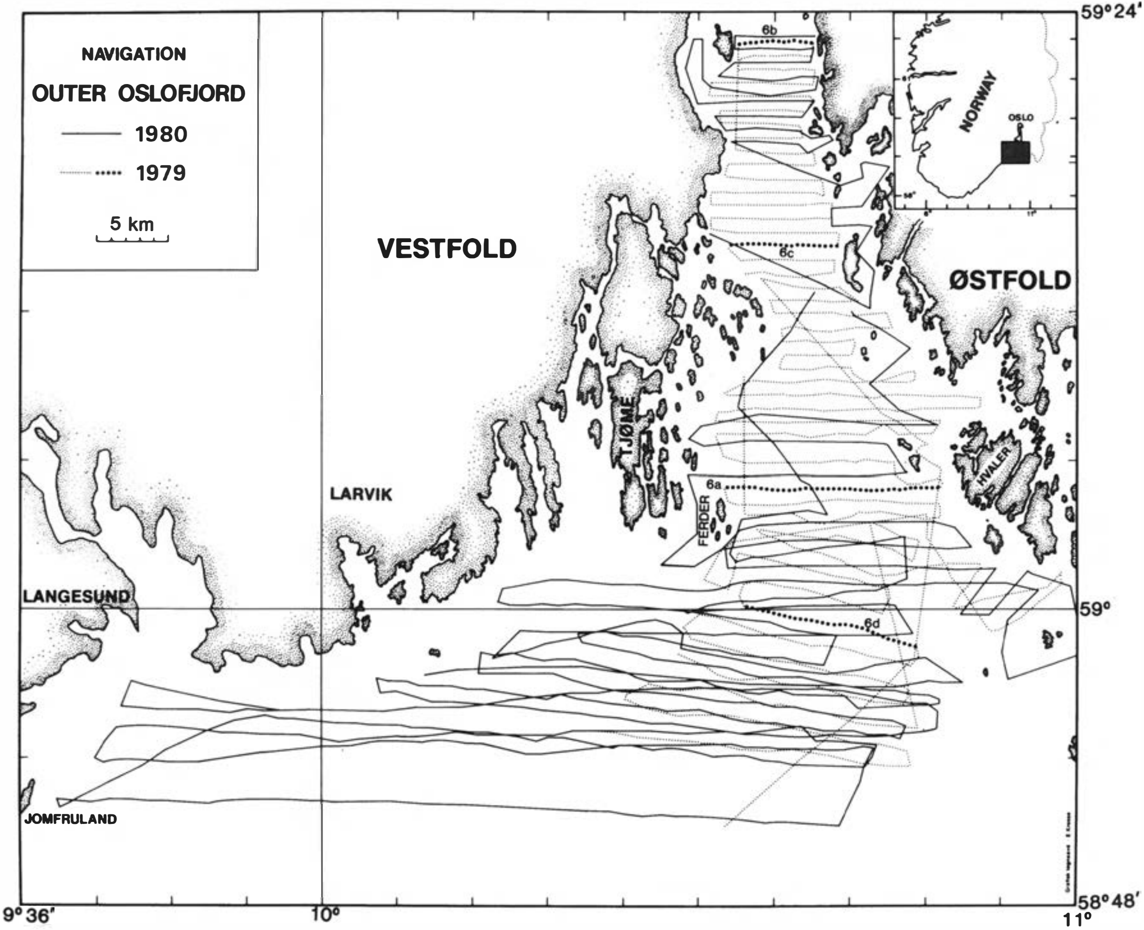


Fig. 2. Cruise track 1979 and 1980. Numbers 6a–6d on heavy, dotted lines refer to shallow seismic profiles presented in Fig. 6.

(Hageskov 1981), and is slightly younger than the surrounding gneisses (Flodén 1973).

- Permo-Carboniferous lavas (Olaussen 1981), mainly situated in the northwestern part of the survey area, but also found in some smaller areas in the Skien-Langesund area. The lavas consist of a number of rhomb-porphyritic, basaltic and trachytic flows, mostly of more or less local origin (Oftedahl & Petersen 1978).
- Permian intrusive body of larvikite in the southwest. This monzonitic rock is one of the major plutonic rock types in the Oslo graben, and defines a distinct southern plutonic region (Ramberg 1976).
- Permian rhomb-porphyry conglomerates which form some of the islands on the east side of the Oslofjord. According to Larsen et al. (1978), these sediments were deposited as alluvial fans of mainly volcanic material from the elevated graben shoulder to the east.
- Cambro-Silurian rocks of the Skien-Langesund area, consisting of a more or less continuous lower Paleozoic section of layered limestones and shales.

Structural lineations are mainly confined to the sectors north-northwest to north and north-northeast to northeast, although several trends occur. These main trends were probably defined by zones of weakness before the different stages of the Permo-Carboniferous evolution of the Oslo graben took place (Ramberg & Larsen 1978). In Fig. 1 only main faults/fractures inside the coastline are drawn, except for the major Oslofjord fault.

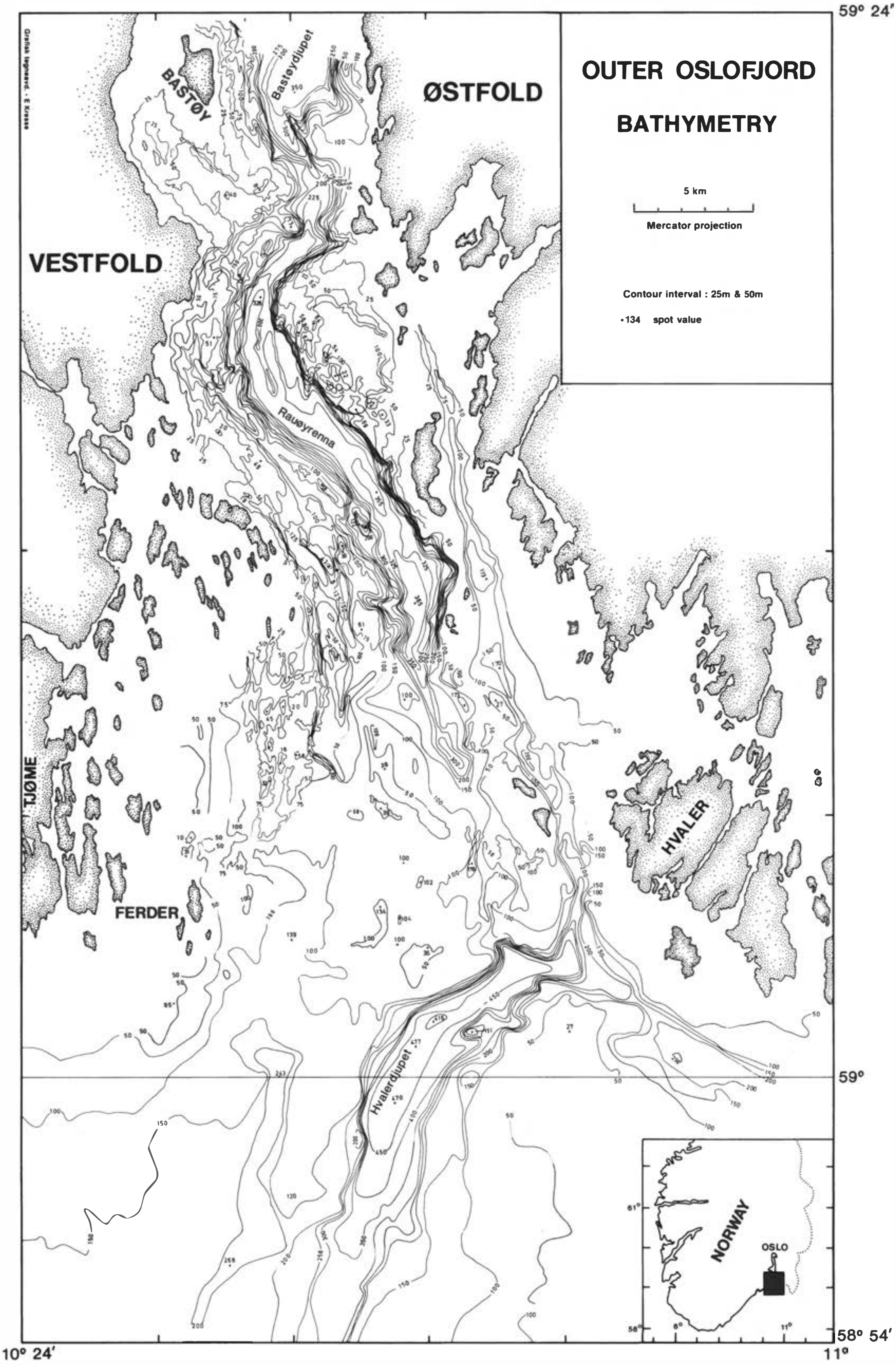


Fig. 3. Bathymetry of the outer Oslofjord. See text for data sources.

Quaternary

The Quaternary history of the Oslofjord-Skagerrak area is characterized by oscillating ice sheets, extending out from central Fennoscandia. At the end of the Late Weichselian, the ice front retreated rapidly northwards. The survey area, from Hvaler islands and northwards (Fig. 1), was deglaciated from 12,300 years BP to 10,700 years BP (RA sub-stage) (Sørensen 1979). The retreat took place in a stepwise manner with stops and minor readvances, producing marginal deposits, end moraines and ice-front deltas. Considerable amounts of glaciomarine sediments (mostly clays) were deposited more distally to the retreating ice front.

During and after the retreat of the ice sheet, isostatic rebound and eustasy caused a relative vertical shoreline displacement varying from 150 m (near Larvik) to 220 m (100 km north of Oslo). Due to this regression, marine sediments were exposed to current and wave activity, eroded, transported and redeposited at greater water depths (Roaldset 1979).

A considerable part of southern Norway is drained via outer Oslofjord into Skagerrak. The Oslofjord near-shore sediments consist mainly of material derived from glacial deposits and brought out by rivers, as defined by a high illite and chlorite content in the clay fraction (Roaldset 1979). Nearby in the Skagerrak, however, a relatively high content of smectite and kaolinite shows the influence of the counter-clockwise Jutland current system, because these clay minerals originate from Mesozoic and Tertiary sediments in Denmark, southern Sweden and the North Sea (Rønningsland et al., in prep.).

Bathymetry

A bathymetric map of the outer Oslofjord has been compiled (Fig. 3). The northern half of the map is based on soundings made by the Norwegian Hydrographical Survey during the period from 1961 to 1978. Due to close line spacing, this part has a contour interval of 25 m. The southern half is based on soundings from the cruises in 1979 and 1980. As the data density is more sparse in this area, a contour interval of 50 m is used. Areas not covered by the two cruises (i.e. closer to the shore) have not been contoured.

The Oslofjord consists of a number of silled basins. Predominant in the outer fjord are three deep basins, Bastøydjupet, Rauøyrenna, and Hvalerdjupet, separated by two thresholds of which the southernmost, the Ferder sill, is the shallower and more distinct. Here the seafloor is also highly irregular (with a relief of 10–30 m).

The major basins are characterized by steep slopes and relatively flat bottoms (due to Quaternary deposition) with waterdepths of more than 300 m. To the sides of the basins, the waterdepths are usually less than 100 m. The slopes often show a stepwise pattern (Fig. 6c). In the two northernmost basins the eastern slopes are the steepest, while the opposite is true for Hvalerdjupet. The west slope of Hvalerdjupet has in some places a gradient of 40 degrees. While Bastøyrenna and Rauøyrenna are markedly silled, Hvalerdjupet shallows more gradually towards the southwest, towards the deeper waters of the Skagerrak.

Apart from these major features, there are a number of smaller basins and shoals that commonly have northwesterly, northeasterly and more northerly trends, which also are the main structural directions of the Oslofjord area.

East of the main basins is an elongated trough, running between the rhomb-porphyry conglomerate islands and the mainland. This trough is usually interpreted as an expression of the Oslofjord fault (Larsen et al. 1978).

Quaternary sediments

Distribution

An isopach map of the total thickness of Quaternary sediments in the survey area has been compiled (Fig. 4), based on the sparker data obtained during the 1979 cruise. No sediment velocity measurements were made, but an estimated mean velocity of 1700 m/s were used to convert travel time to metres.

In general, the outer Oslofjord has a sparse and unevenly distributed sediment cover. The major thicknesses are restricted to narrow zones following the bathymetric lows. This distribution is better seen on Fig. 5, where both the bathymetry and the sediment layer have been plotted perpendicularly to the ship's tracks. In the shallower areas, there is generally sediment present in pockets, surrounded by more or less barren rock faces (Fig. 6a), but the sparker resolution (10–15 m) is a limitation for mapping thin sediment cover. It should be noted that it may some-

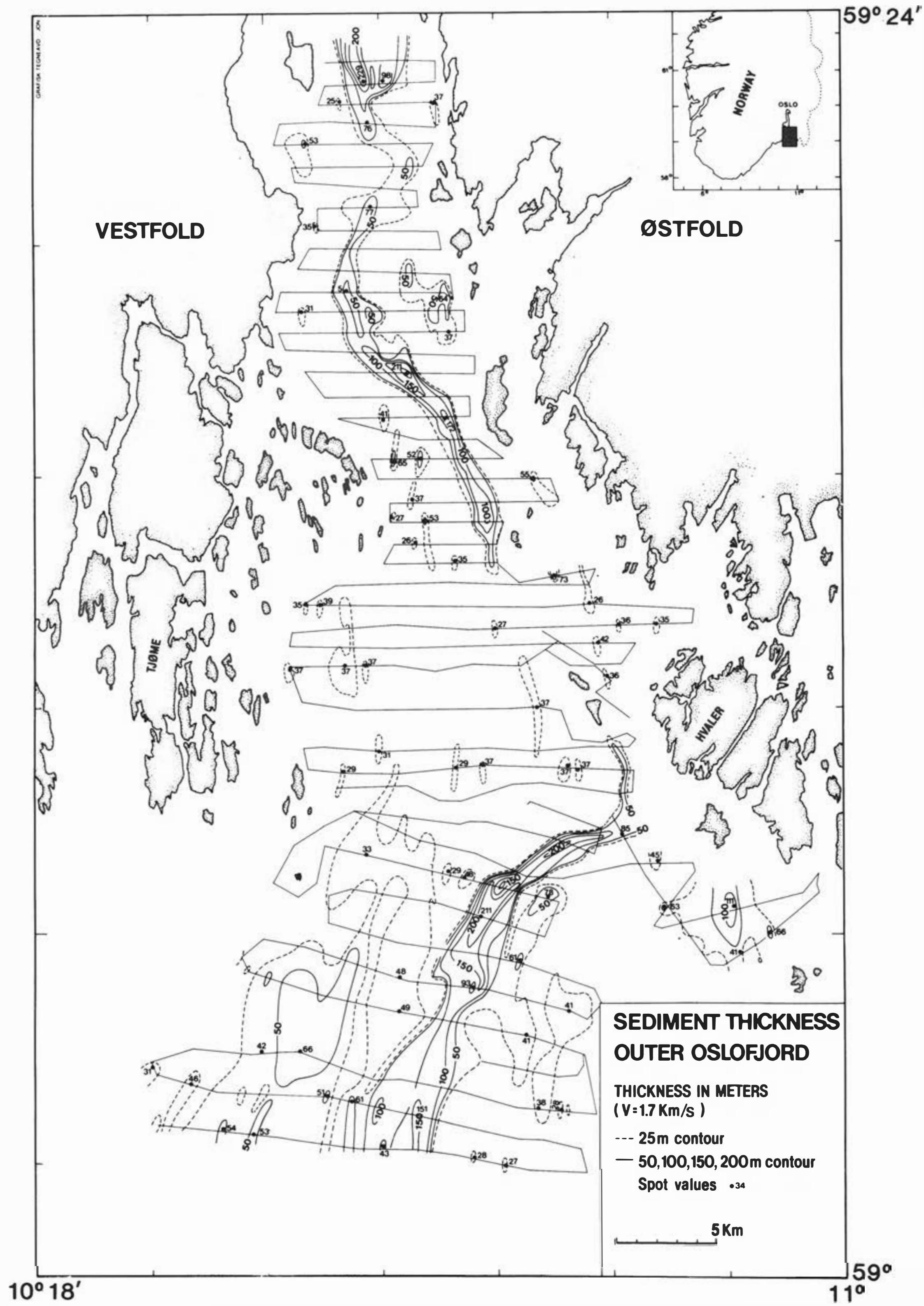


Fig. 4. Thickness of Quaternary sediments, based on the sparker profiles of 1979.

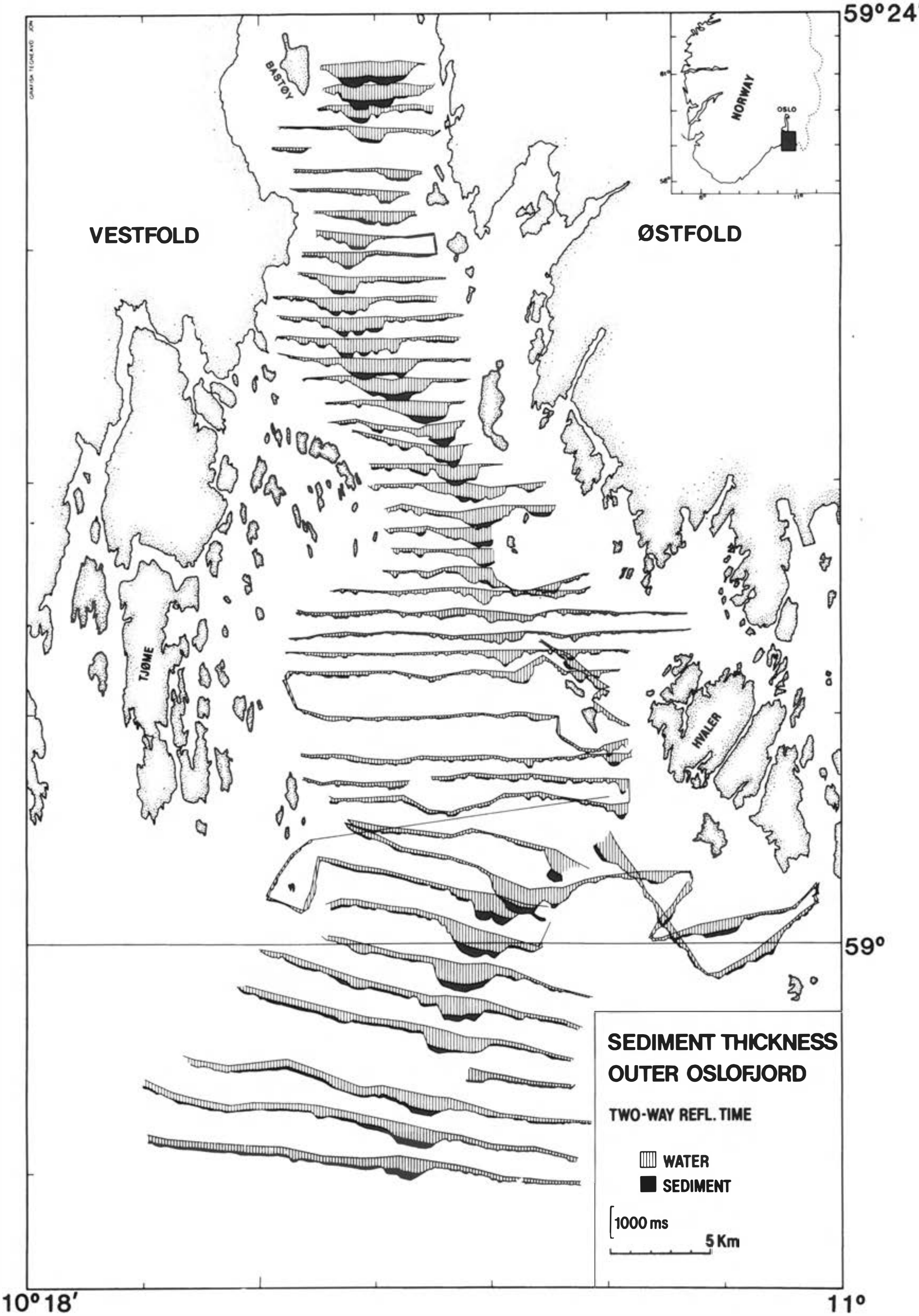
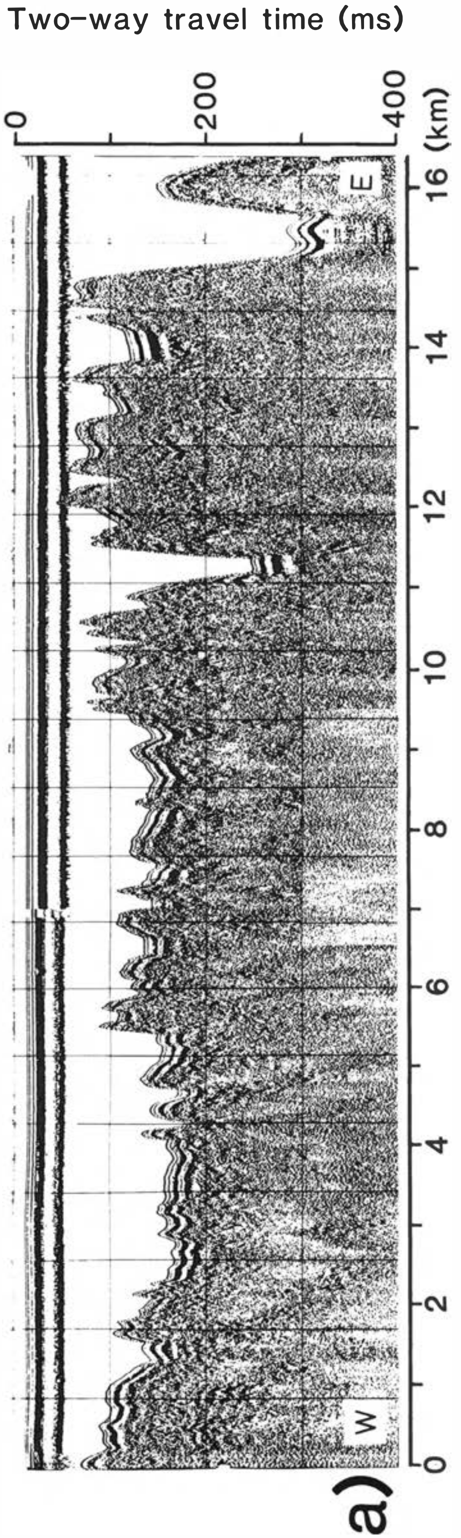


Fig. 5. Bathymetry and sediment thickness, plotted perpendicularly to the 1979 profiles.



times be difficult to distinguish between bedrock and highly compacted moraine from shallow seismic reflection records alone. However, the sharp relief and lack of internal structures suggest that there are no significant morainic deposits in the shallower areas surrounding the main basins.

The largest sediment accumulations are found in the three major basins, with thicknesses exceeding 200 m. The shallow Ferder sill has the least sediments. Further to the south where the water generally gets deeper and the bottom topography more even, the sediment cover is more continuous, but still with the thickest accumulation in the Hvalerdjupet basin. Previous work south of Larvik shows that at greater than 150 m water depth, the crystalline basement is covered by a continuous sediment layer (Rønningsland 1976).

Three main sedimentary units can be distinguished (Fig. 6b–d):

1. The uppermost unit is an acoustically transparent sediment layer with no internal reflectors, varying in thickness from a few milliseconds (two-way travel time) in shallow sediment pockets, to approximately 130 ms in Hvalerdjupet. In the other deep basins, the top layer is about 40 ms thick. According to Richards (1976), this material consists of "a greyish, silty clay with high plasticity", a description consistent with the acoustically transparent character of the sediments.
2. An intermediate, acoustically more layered sequence, with thicknesses up to 100 ms (Hvalerdjupet). This unit is only found in the deeper basins and troughs. The individual layers are relatively smooth and can be followed across the basins. Both this unit and the top one reflect the underlying topography.
3. A lower unit, up to 80–90 ms thick, starting with a marked reflector, is seen at ca. 0.5 s in Fig. 6b and ca. 0.6 s in Fig. 6c. This is the least transparent of the three units. Internal diffractions, which may indicate larger stones and boulders, can be seen in this layer in Rauøyrenna (Fig. 6c). In Bastøydjupet (Fig. 6b) it may be divided into an upper unit of the same character as in Rauøyrenna, and a lower, layered unit.

Fig. 6. Shallow seismic (sparker) profiles across. a) the Ferder-sill. b) Bastøydjupet (heavy signal in lower right is noise). c) Rauøyrenna. d) Hvalerdjupet. For location, see Fig. 2.
Fig. 6a

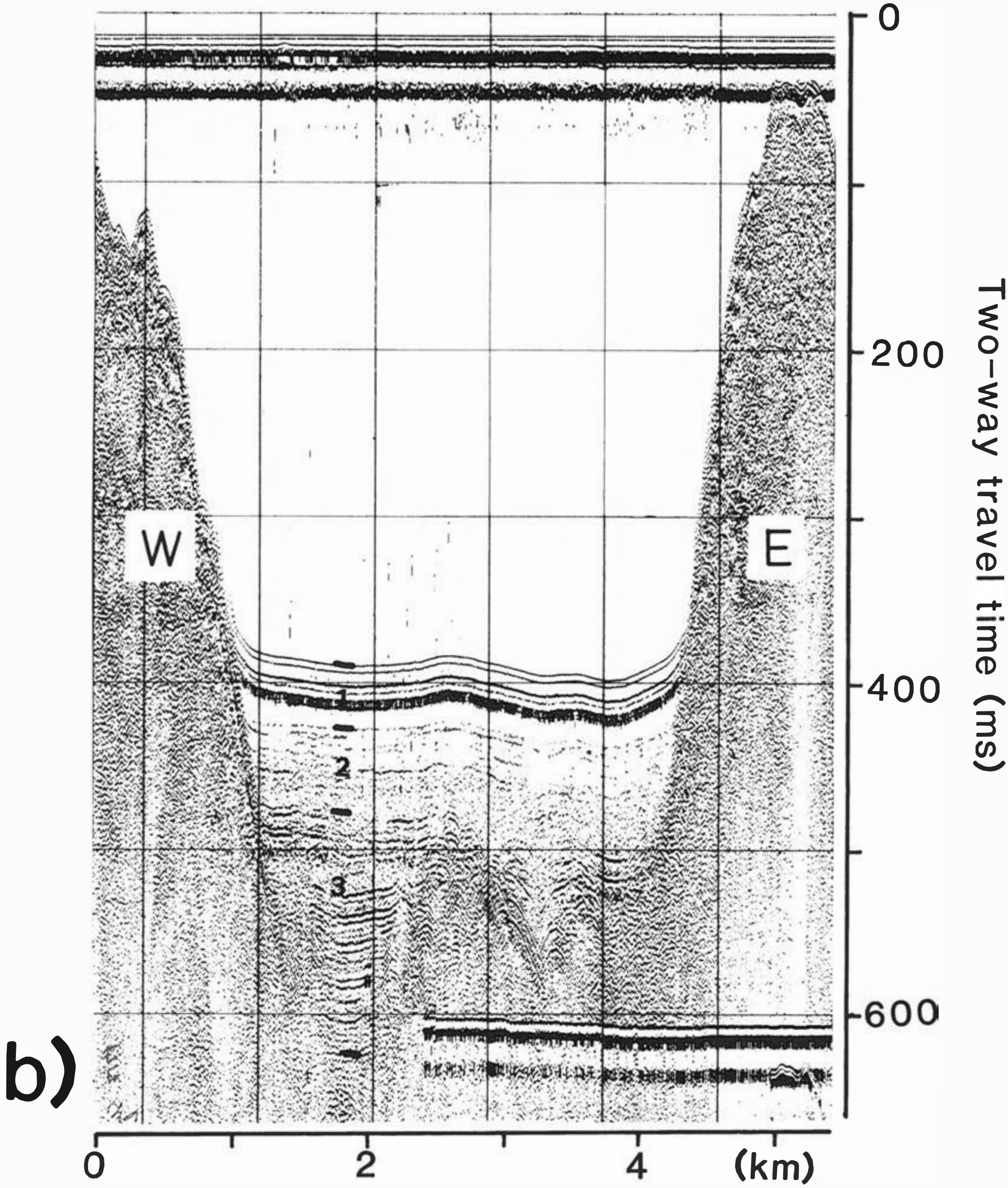


Fig. 6b

The lower sequence cannot be distinguished in Hvalerdjupet (Fig. 6d), and the whole accumulation seems to consist of the two upper units.

Earlier profiling in the outer Oslofjord, using a low frequency echo sounder, have given sediment thickness of less than 60 m in Bastøydjupet and ca. 40 m in Rauøyrenna (Richards 1973, 1976). The 1979 profiles presented here suggest that the total sediment thickness in these troughs is considerably larger. The echo sounder in the previous study has obviously not been able to penetrate through the intermediate unit.

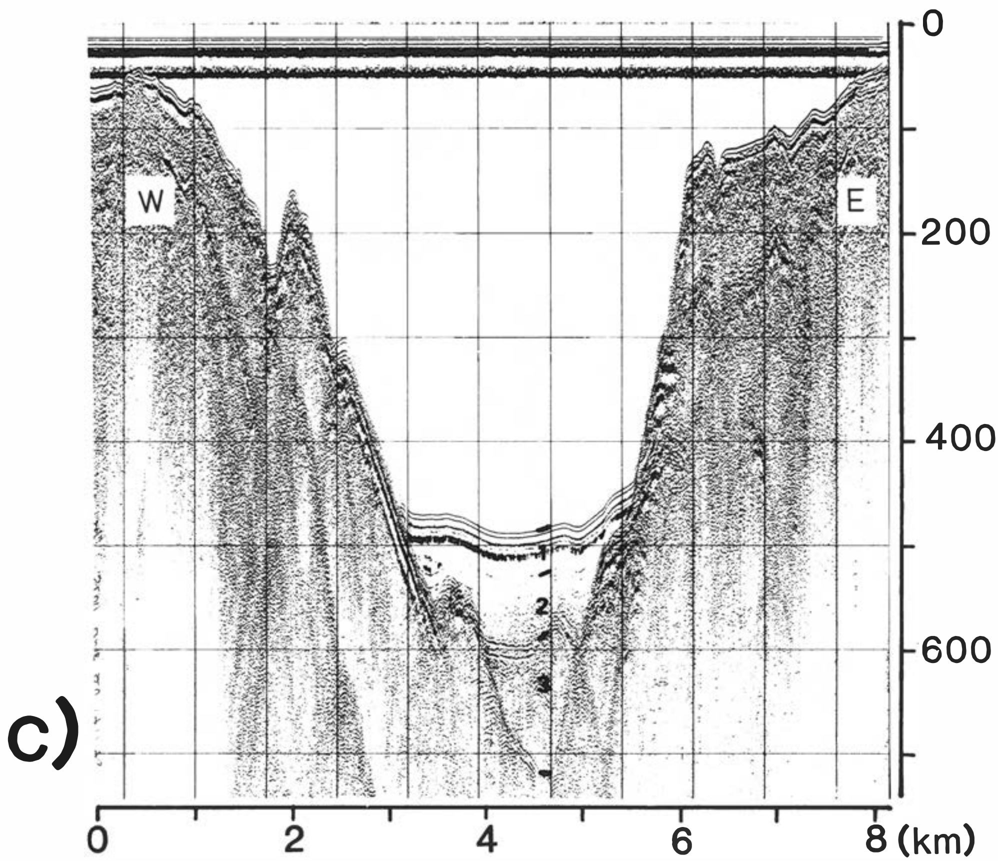


Fig. 6c

The seismic stratigraphy matches fairly well with seismic refraction measurements made by Øfsthus (1966) just north of the survey area.

Layering can also be seen in smaller, local basins outside the major troughs, but in these areas the sediments can only be divided in two units based on the sparker records. Recent velocity measurements in some of these areas (J. I. Faleide, pers. comm.) have given velocities of approximately 1500, 1700 and 1900 m/s. This is considered to indicate that the same sedimentary units as seen in the main basins are also found outside of these. However, the different units are thinner and the whole sequence is only locally developed.

Deposition

The upper, transparent unit is considered to represent the Holocene (although a late glacial age for part of it cannot be excluded), assuming water velocity (1500 m/s) gives about 30 m thickness in the two northern basins, and up to 100 m in Hvalerdjupet. It is probable that a relatively great part of these sediments were deposited during the first two–three thousand years of the Holocene, when relative lowering of the sea level was most rapid. During this period extensive submarine areas were exposed to wave action, leading to erosion and redeposition of marine sediments further out in the fjord. Another important effect of a sea level fall is lowering of the erosional base and thus an increase of the eroding and transporting capacity of rivers. This again results in a larger sediment input to the fjord.

Arguments for the greater thickness of unit 1 in Hvalerdjupet are twofold. Firstly, this area probably received more sediments from the Norwegian mainland than the other two basins. This is mainly because of the major Glomma river, terminating north of the Hvaler islands. Second-

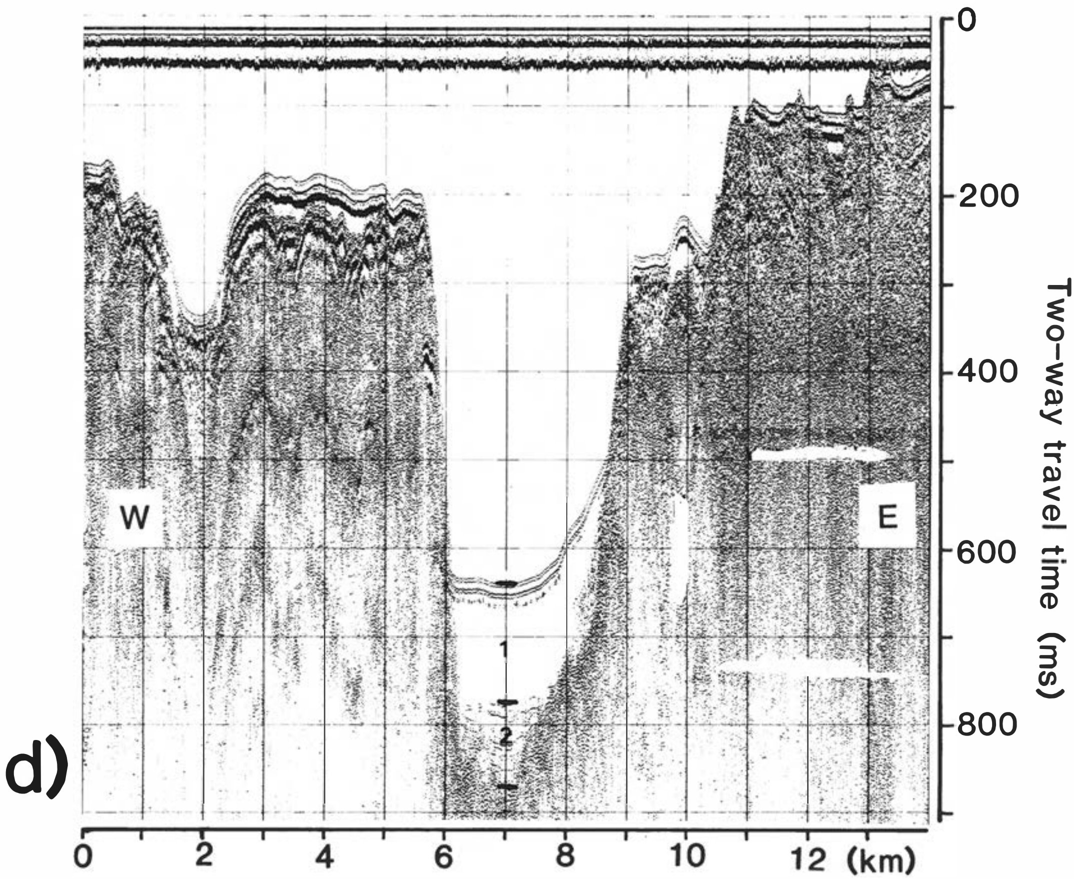


Fig. 6d

ly, this area probably also receives sediments from the south, brought in by the counter clockwise Jutland current, which is the main current system of the Skagerrak (Svansson 1972). Along the Swedish coast, recent sedimentation rates of 30 mm/year have been measured, and this is mostly material brought in by the Jutland current (Fält 1982). A southerly sediment source may also explain the more continuous sediment cover in the southern part of the survey area.

Seismic profiles across Hvalerdjupet (Fig. 6d) show an asymmetrical distribution of unit 1 sediments. Apart from the less steep basement slope on the east side of the basin, the higher sediment surface on this side most likely reflects a main sediment supply from east and northeast. However, sediment transport from the south, under the influence of the Coriolis force, may also be a factor. It should be noted though, that with current velocities sufficiently high to cause non-deposition or erosion, the asymmetry pattern could indicate a main transport direction southwards through the basin. Due to the homogeneous character of the unit 1 sediments, the latter is, however, considered unlikely.

Further north in the fjord, there is less well-defined asymmetry in the sediment surface of the basins, and it may vary from east to west. This distribution is somewhat dependent on the underlying bedrock topography but may also indicate local variations in the current pattern.

Assuming a velocity of 1700 m/s for unit 2 implies a thickness up to 45 m in Bastøydjupet and Rauøyrenna, and 85 m in Hvalerdjupet. We propose that this unit was deposited quite rapidly under ice-proximal conditions, probably beginning when the grounded glacier ice started to float over the deeper basins. Diffractions, which may be interpreted as larger, ice-dropped stones, may be seen especially in the lower part of this unit. The lower part of the unit has also less well-defined layering than the upper part. A maximum of 3000 years may tentatively be given for the duration of the depositional regime proposed for this unit.

In Kongsfjorden, Spitsbergen, sedimentation rates of 10 cm/year have been measured from varves in basins outside a currently active glacier (Elverhøi et al. 1980). Although the sedimentary bedrock of Spitsbergen is easier to erode than the bedrock of the Oslofjord area, both areas have or have had large amounts of loose, glacially derived material, which is easily eroded by waves and rivers. The high sedimentation rates needed to deposit unit 2 during a time interval of approximately 3000 years is not improbable in this environment. Even higher sedimentation rates are reported from other present-day glaciated areas (Molnia & Sangrey 1979, Powell in press).

The deepest unit may consist of a wide range of sediment types from a rather wide time span. The velocity of 1900 m/s in a smaller, local basin may indicate that morainic material is present. The diffractions and lack of reflectors in Rauøyrenna support this, but it might also be due to rapid deposition, for instance near the grounding line of a floating glacier. Older, pre-Weichselian sediments cannot be excluded either, especially in the bottom of the deep basins. The deepest, layered sequence in Bastøydjupet (Fig. 6b) might be such older sediments. The layering could however also reflect climatic fluctuations during the Late Weichselian glacial retreat, resulting in glacier oscillations and/or differences in the fallout from the glacier.

The lowest unit in Rauøyrenna is suggested to consist of morainic material, deposited during the later glacial phases, when the glacier was relatively thin in this area. Under the effect of buoyancy, the compaction of the sediments from ice-loading would be rather low. This may explain why the sparker so easily penetrates down to the basement.

In Bastøydjupet, it is probable that the lower, layered unit represents older sediments, compacted by the Weichselian ice, with a cover of the same type of morainic material as is suggested for Rauøyrenna.

Work done by Van Weering et al. (1973) and Van Weering (1975, 1982) has shown four depositional units further out in the Skagerrak. Our intermediate unit may resemble unit 2 of these surveys, which is also interpreted to be of Late Weichselian/early Holocene age. The layering in Van Weering et al.'s (1973) unit 2 is thought to be due to tidal circulation after the rise in sea level. Tidal activity may also have played an active role in the formation of the layering, especially in the upper part of the second unit in the Oslofjord area. However, in this near-shore, and thus ice-proximal environment, differences in output of coarser material from the glacier are considered a more important factor. Ice rafting is important for transporting material away from the glacier, but density overflow may also carry relatively coarse material some distance (Gilbert 1982, Elverhøi et al. 1980).

Magnetic measurements

Magnetic total intensity has been plotted along the profiles for both cruises (Figs. 7 & 8). The northern half of the survey area has a quiet magnetic field which is of limited use in identifying geological boundaries. These northern profiles (Fig. 8) should, however, cross three different types of bedrock: Precambrian gneisses, Permian lavas, and Permian sediments. The quiet field is also confirmed by the aeromagnetic map of the area (Nor. geol. unders. 1973). Åm & Oftedahl (1977) interpret the eastern Vestfold Permo-Carboniferous lavas to be underlain by almost unmagnetic Precambrian rocks, and not Larvikite. It is, however, reasonable to expect a sequence of Cambro-Silurian sedimentary rocks between the lavas and the Precambrian basement. This should not change the character of the magnetic field.

Between Rauøy and Hvaler islands there is an area of strong magnetic anomalies. The Permian rhomb-porphyry conglomerates found on the small islands along the east side of the fjord are highly oxidized and thus have low magnetization (K. Storetvedt pers. comm.). The fact that the anomalies seem to cross the Oslofjord fault line could indicate that the magnetic sources lie in the Precambrian basement, and that the cover of sedimentary rocks is quite thin in this area. A possible magnetic source body might then be the Precambrian Iddefjord granite. Investigations of the Swedish Bohus granite body, which is connected to the Iddefjord granite (Hageskov 1981), shows that the granite has higher magnetic susceptibility than the surrounding gneisses (G. Lind pers. comm.). However, since the downfaulting along the Oslofjorden fault is interpreted to be largest in its southern part (Ramberg 1976), it is reasonable to expect a thick sequence of

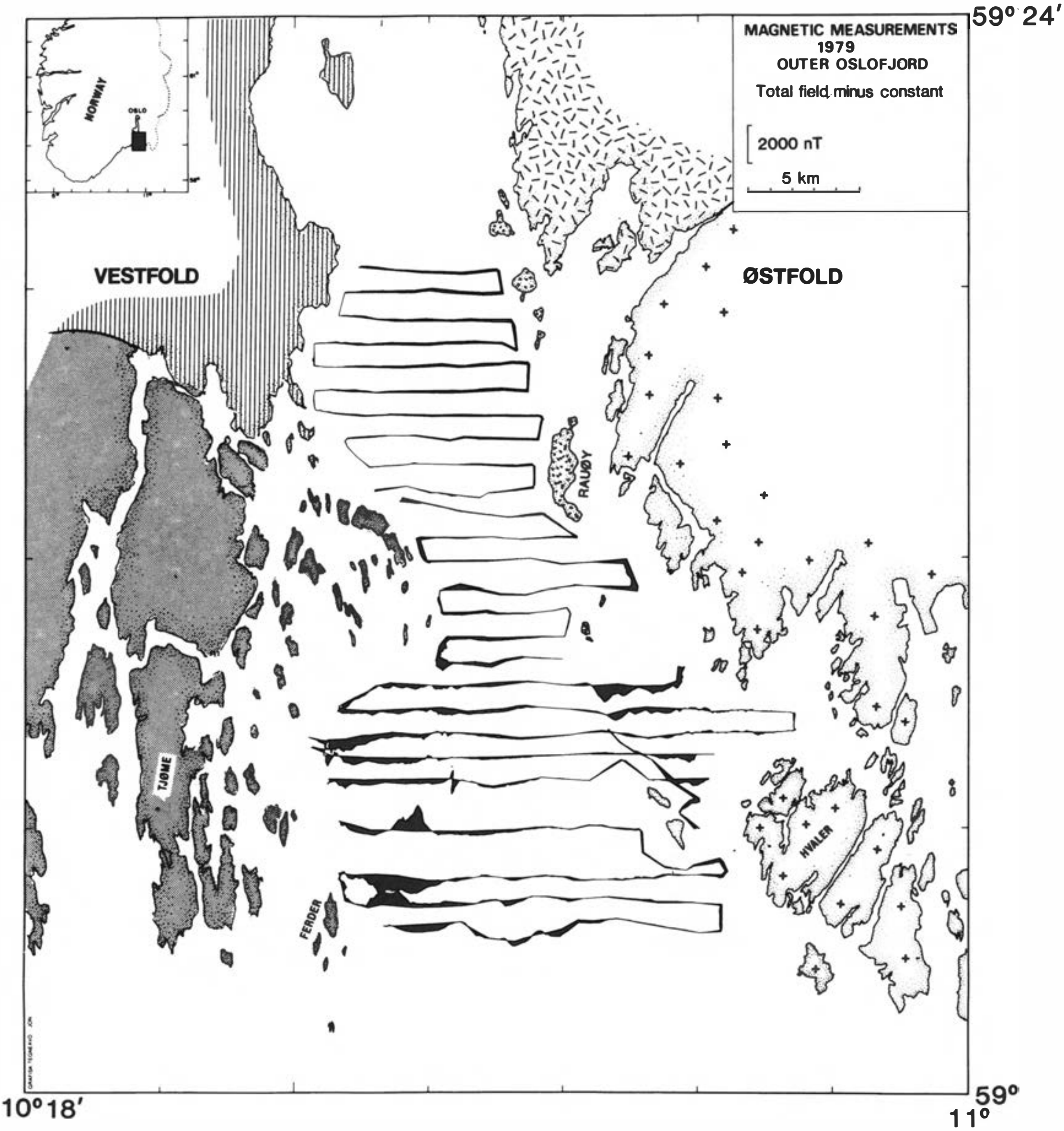


Fig. 7. Profiles of total magnetic intensity of the 1979 cruise, plotted perpendicular to the ship's track after subtraction of a constant value of 48000 nT. According to Fabiano & Peddie (1969), 50000 nT is the approximately correct magnitude of the regional field of the area, and the constant offset is due to an instrumental error. See text for further explanation. Legend of land geology in Fig. 1.

sedimentary rocks, both Cambro-Silurian and Permian. Seen from the aeromagnetic map (Nor. geol. unders. 1973), the granite body may cause anomalies, but probably not strong enough to give a distinct character through a thick sedimentary sequence. A more probable explanation is therefore intrusions, rising to some depth below the seafloor, either in the form of a dyke swarm, or an intrusive body. In the two cases both sides of the fault must be affected. If not, the fault must be situated farther to the east (Fig. 1), which is unlikely from the bathymetry of the area (Fig. 3).

The magnetic field intensity is also slightly high south of the Hvaler islands, indicating a continuation of the Iddefjord granite in this di-

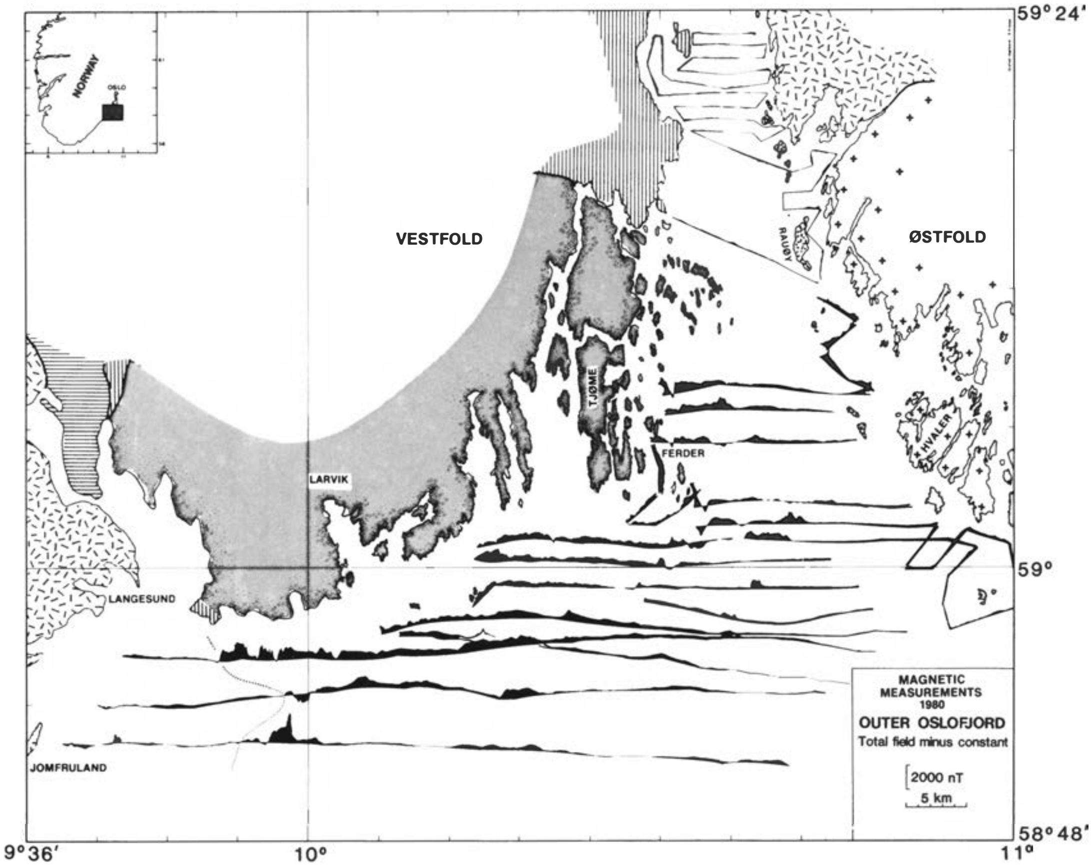


Fig. 8. Profiles of total magnetic intensity of the 1980 cruise, plotted perpendicular to the ship's track after subtraction of a constant value of 50000 nT. Dotted line in the southwest indicates boundary between magnetic and non-magnetic rocks. See text for further explanation. Legend of land geology in Fig. 1.

rection but not as far as Torbjørnskjær (Fig. 1), where no granite is exposed (B. Larsen pers. comm.).

From the islands of Bolærne southwestwards to southeast of Langesund there is an area of irregular magnetic field and large anomalies. This is interpreted to define the outline of the Vestfold Permian Larvikite intrusive. The boundary to the less magnetic rocks is clearly seen as a transition into a smoother magnetic field. The irregular appearance of the field in the Larvikite area could be due to susceptibility variations (i.e. variations in the magnetite content). The large anomalies east of Tjøme may thus be caused by large scale layering of magnetite as suggested by Åm & Oftedahl (1977). The appearance of the anomalies, however, also seems to indicate a certain dip of the layers.

About 10 km southeast of Ferder there is a rather sharp positive, doublepeaked anomaly, recognized on several profiles and paralleling the Hvaler trough to the west. A simple model which roughly fits the anomaly is that of two bodies with a susceptibility contrast of 0.006, extending downwards at least 600 m. Two subparallel dykes are suggested to be the cause of the anomaly.

Bedrock geology and structures

A simple structural map (Fig. 9), showing main geological boundaries and different faults and fractures, has been compiled from the seismic and magnetic data.

As mentioned, the outline of the Larvikite is fairly well defined from magnetic measurements.

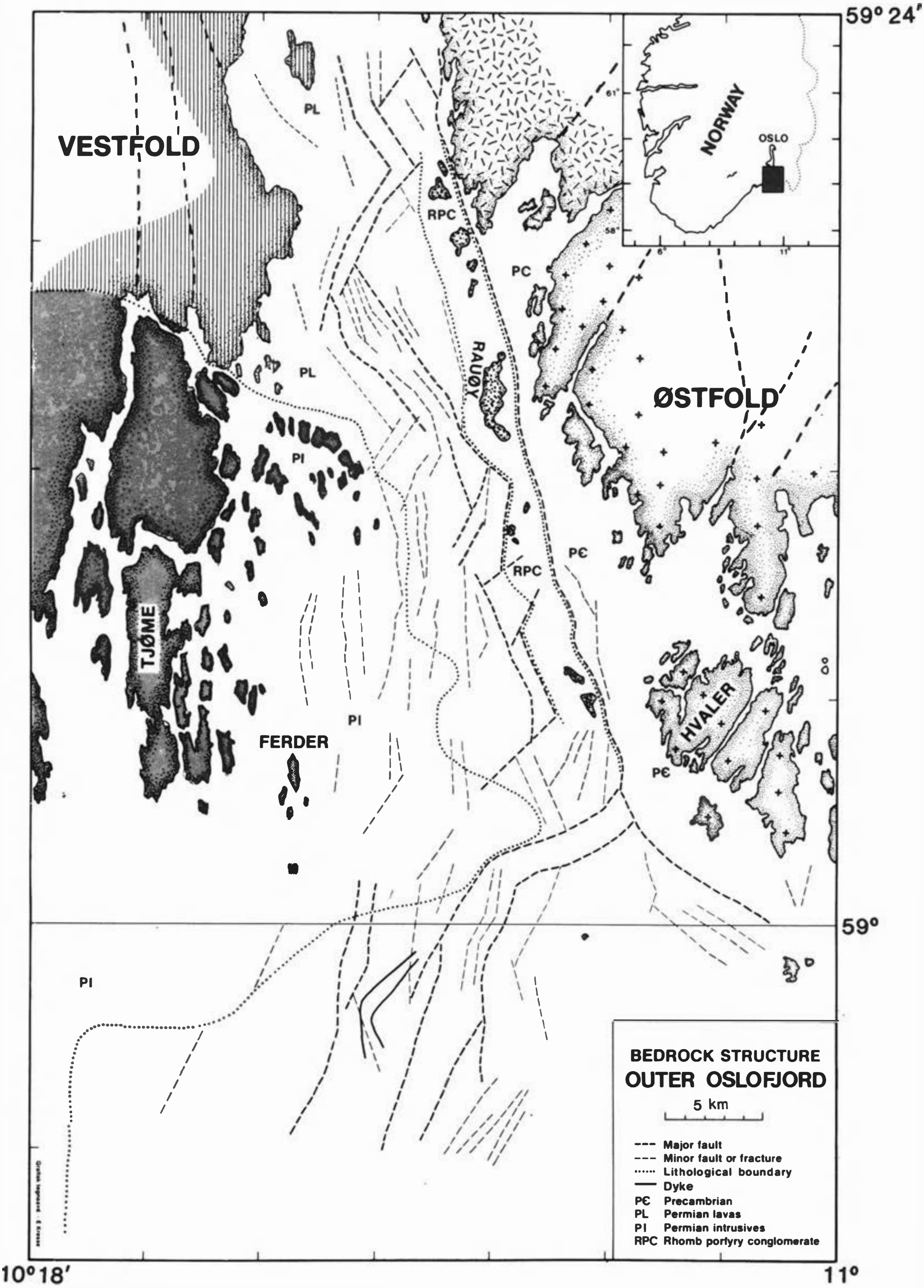


Fig. 9. Simple map of outer Oslofjord bedrock structure, based on data obtained during the 1979- and 1980-cruises. Legend of land geology in Fig. 1.

The western boundary, towards what may be Cambro-Silurian sedimentary rocks, is shown in Fig. 8. However, since Permian lavas are exposed also west and southwest of the intrusives, it cannot be excluded that the indicated boundary might be between Permian intrusives and volcanics.

The rhomb-porphyry islands on the east side of the fjord are all lying on a ridge, especially well defined in the southern half (Fig. 3). This ridge is interpreted to consist of the same material as the islands. Both the northward and the southward continuation of the sediments are uncertain, but they are not found on the island of Jeløya (Larsen et al. 1978).

The Permo-Carboniferous lavas of Vestfold are suggested to continue over most of the fjord in the northernmost area, underlain by Precambrian gneiss and Cambro-Silurian sediments.

Nothing definite can be said about the zone between the rhomb-porphyry conglomerates and the Larvikite, but a probable interpretation may be a continuation of the lavas in this area. It seems further reasonable to suggest that these lavas might be interbedded with sediments of a more distal facies, in relation to the graben shoulder to the east, than what is found on the islands.

In the southeastern part of the survey area, the seismic profiles show a somewhat different basement character on either side of Hvalerdjupet (Fig. 6d). The west side has more large-scaled basement topography, and has also a greater water depth than the east side, indicating a different type of bedrock. On the east side, a Precambrian basement seems reasonable. This may either be gneiss or, most probably a continuation of the Iddefjord granite. Dredging the slopes of Hvalerdjupet could probably give a more definite answer. On the west side, we assume Permian lava is the most probable bedrock.

On the assumption that most elongated topographic features in the ara are caused by faults and fractures, basement topography has been used for mapping of these structures in the fjord area. Because no displacement can be recognized on the seismic records, the interpretation is tentative, and the division between major and minor faults or fractures (Fig. 9) is done only from the size of the topographic features. The outline of the main eastern fault, the Oslofjorden fault, is taken from earlier published maps (Larsen 1975) wherever there is lack of profile coverage.

The data base is too limited for a detailed structural interpretation of the area. Therefore no direction of movement is indicated along the faults. However, it is probable that the major troughs owe their formation to downfaulting, forming a small scale basin and range pattern, later modified by glacial erosion. It should be mentioned, though, that the northern part of Hvalerdjupet has a somewhat peculiar bathymetric expression (Fig. 3). Sharp, northwesterly trending bends in the slopes on both sides are fairly well aligned with the trough running southeastwards to the south of the Hvaler islands. This pattern could be indicative of a strike-slip motion (although not shown in Fig. 9) which might be partly responsible for the formation of Hvalerdjupet as a small pull-apart basin.

The structural pattern elsewhere in the fjord follows the main structural directions on land in the area: north-northwest, north-northeast, and more northerly direction as expected. The more northerly direction seems to be most common in the area interpreted as occupied by Larvikite.

Summary

The outer Oslofjord has three major bathymetric basins. The two northernmost, Bastøydjupet and Rauøyrenna, are markedly silled, while the third, Hvalerdjupet gradually opens into the Skagerrak. The basins have steep, stepwise slopes and are probably formed by graben-faulting and later modified by glacial erosion. Strike-slip motion is suggested in the southeastern part.

The major accumulations of Quaternary sediments are restricted to the basins, where they exceed 200 m. Three main units can be distinguished; an upper acoustically transparent, supposed Holocene unit, an intermediate, layered supposed Late Weichselian unit and a lower unit, probably consisting partly of moraine and partly of older, pre-Weichselian layered sediments. In Hvalerdjupet, only the two upper units are recognized. Here, the distribution and larger thickness of the Holocene unit may indicate that material is also brought in from south with the Jutland current.

From magnetic and seismic profiling the following inferences can be made about the submarine bedrock geology:

- The Permo-Carboniferous Vestfold lavas cover most of the northern part of the survey area

and are underlain by rather nonmagnetic rocks.

- Large anomalies along the edge of and inside the Permian Larvikite make it possible to map the outline of this intrusive body.
- Permian rhomb-porphyry conglomerates are probably restricted to a ridge along the main Oslofjorden fault, but Permian sediments, possibly interbedded with lavas, may also be found west of the ridge.
- The Iddefjord granite probably extends farther to the southwest from the Hvaler islands.
- Intrusives are suggested to be present northwest of Hvaler, at some depth (either as a dyke swarm or as a body), and as two subparallel dykes west of Hvalerdjupet.

The submarine structural pattern shows the same directions as mapped subaerially.

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